Technology 2003, Anaheim, CA, Dec 7-9, 1993

Name: **Dr. Paul S. Schenker (1)**
Dr. Antal K. Bejczy (2)

Position/Title: Group Supervisor, Man-Machine Systems (1)
Technical Manager, Teleoperation, and JPL Sr. Research Scientist **(2)**

Affiliation: Jet Propulsion Laboratory, California Institute of technology

Address: Jet F'repulsion Laboratory
4800 Oak Grove Drive / MS 198-219
Pasadena, CA 91109

Phone: (818) 3542681

FAX: (81 8) 3935007

EMAIL: schenker@telerobotics.jpl.nasa.gov (Internet)

Gov't Agency: Work performed for NASA (Code C)

Contract No.: UPN 55-586-01-11

Paper Title: **Advanced Teleoperation: Technology Innovations and Applications**

'Description:

(()\'cl'View)

Teleoperation is the. remote performance of a task under direct manual control of a human operator. Teleoperators are valuable assets for hazardous work in unstructured environments, which increasingly include nuclear-hazardous materials handling, underseas exploration & salvage, mhic-assisted surgery, and space operations. A related technology and applications area is *virtual reality and virtual environments*; e.g., the operator commands a modeled, rather than physical robot, in a computer-generated workspace. Indeed, such graphics-based virtual environments provide useful tools for teleoper at or simulation and system design, including task analysis, operator training, and on-line task prediction. ***Advanced teleoperation***, which we report innovations and applications of here, emphasizes the coupling of advanced real-tilnc computing 10 manual teloperation: through the intelligent interface of human perception, spatial planning, textual & graphic skills, anti manual dexterity to I)n-line. interactive computing aides, a telerobot operator can under take a wider spectrum of more complex tasks, generally wth increased efficiency and safe.ty. We have developed and report on related *technology products* that include real-time 3-1) calibrated graphics displays, task visualization & planning systems, and shared manual-automatic controllers for high-degree-of-freedom robots utilizing multi-mode sensory input. Wc have established commercial technology capture for the control architectures and algorithms, and are pursuing same for the graphics displays. We are also seeking *new applications of advanced teleoperation technology* beyond the mai n NASA emphasis of dexterous space servicing (per below), anti one area of potential interest is robotic microsurgery, e.g., as might support high-dexterity, highly tactile, small-scale procedures for vitr co-retina] and stereotactic cranial surgery.

(Technical Background)

Our work in teleoperation highlights its space applications, and relate.ci tasks such as remote platform servicing, telescience, and lunar exploration[1]. These tasks arc complex, time-consuming, and relatively unstructured. Demands for manual dexterity are often high; the work is fatiguing; and uncertainty, which includes effects of time.-(ielay, is nearly always present, In the face. of these problems, we have been working along several technical fronts which include redundant telemanipulator control, mul(i-camera viewing and real-time graphics simulation, integrated operator interface design, and syste.ms-scale ground laboratory experiments. WC reported some of these technology developments in [?]. Our main experimental thrust is end-to-end performance charade.riz.aticm -- formal experiment design, task instrumentation for real-time data capture, integra(-c.cJ system demonstrations, and human factors analysis. Collectively, the goal is to quantify operator limitations, component technology requirements, anti their interdependencies, all in the context of meaningful tasks with realistically posed system-level operational constraints (lighting, task geometry, time-clc.lay, control & communication bandwidths, viewing & display limitations, etc.). Accompanying technical issues arc reduction of operator error, workload, and training, each in itself a significant risk and cost driver for space operations. Toward these ends, wc. have been emphasizing advanced approaches to teleoperation, in the functional areas of task perception, planning, and control. The *advanced teleoperation* concept[1 1 is one of computer-assisted telemanipulation, wherein the operator remains in manual control of the task, but with extended functional capabilities and reduced cognitive complexity of task interaction. Computer assists may encompass interactive planning/simulation aids[3], programming/command/status interface.s[fl], and man-machine interactive mode.s of sensor-bascel control, e.g., "shad compliance control"[2, and refs. therein]. Advanced teleoperation often also entails sensory fusion and/or decentralized control, given that sensing, planning, and control functions arc inherently shared between operator and computer [5]. In the controls area, we have developed a variety of kinesthetic position, rate., force-fe.dback, and active compliance modes for teleoperation[6, and refs therein]; these were first applied to dual six degree of freedom (d.o.f.) manipulators and are now being implemented on new 8 d.o.f. offset-axis redundant manipulators[7]; wc have comparatively c.valuated these control modes, along with more traditional position and rate approaches, through simulated space servicing with a dual six degree-of-freedom arm teleoperator. We (ic.scribe experiments in which we re-enacted Solar Maximum Mission sate.iitc. repair procedures, as were originally performed by astronaut extra- vehicular activity (EVA) during a 1984 space shuttle flight[6]. Our recent control designs include computer-interactive redundancy planning and dexterity allocation for the eight d.o.f. manipulator [7], and we outline this. Other supporting developments arc real-time. graphics environments which allow operators to animate, analyze, and train on teleoperator tasks [2, 3]. in this area, we overview a 6-d. o.f. teleoperation virtual reality simulator which not only includes calibrated 3-D kinematics anti viewing (with respect the actual environment being vie\\'cd/sillLLlatcci), but also incorporates modeled contact dynamics with both visual indicators and hand-controller force-fc.cdbad to the operator[3, and refs. tbc.rein]. Wc have recently applied such real-time graphics preview/simulation/predictive displays to simulated robotic servicing of the Hubble Space Telescope, and we will briefly outline this technology demonstration anti its commercial relevance.

ACKNOWLEDGEMENTS

This work was performed at the Jet Propulsion Laboratory, California Institute of Technology, under contract with the National Aeronautics and Space Administration.

(references and figures follow)

REFERENCES

1. A, K, Bejczy, "Sensors, controls, and man-machine interface for advanced teleoperation," Science, Vol, ?0S, pp. 132.7-1335, June 1980; P. S. Schenker, "NASA research & development for space robotics," IEEE Trans. Aerospace Electr. Sys., vol. 24, no. 5, pp. S23-534, September 1988; C. R. Weisbin and M. D. Montemerlo, "NASA's telerobotics lc.search program," to appear in Proc. 1992 IEEE Intl. Conf. on Robotics and Autom., Nice, France, May 199?, and, invited paper for Applied Artificial Intelligence.

2. P. S. Schenker, W. S. Kim, S. C. Venema, and A. K. Bejczy, "Fusing human and machine skills for remote robotic operations," in Sensor Fusion 111: 3-D Perception and Recognition, Pmt. SPIE 1383, pp. ?0?-??.3, Boston, MA, November 1990.

3. W. S. Kim and 1'. S. Schenker, "Teleoperation training simulator with visual and kinesthetic force reality," in Human Vision, Visual Processing, anti Visualization, Proc. SPIE 1666, San Jose, CA, February 1992; also, W. S. Kim, "Graphics displays for operator aid in space telerobotics: task analysis/planning, simulated training, and on-line execution," submitted to IEEE Trans. Robotics and Autom.

4. 1', 1 .ee, A, K. Bejczy, 1'. S. Schenker, and B. Hannaford, "Telerobot configuration editor," in Plot, IEEE Intl. Conf. Systems, Man, and Cybernetics, 1 .os Angeles, CA, November, 1990.

5. S. 1 .ee, E. Zapata, and P. S. Schenker, 'Lll]tcrac.live. and cooperative sensing and control for advanced teleoperation," in Sensor Fusion IV: Control Paradigms and Data Structures (this proceedings), Proc. SPIE 1611, Boston, MA, November 1991; see also, S. 1 .ee, 1'. S. Schenker, and J. Park, "Sensor-knowledge-command fusion paradigm for man/machine systems," in Sensor Fusion 111: 3-D Perception and Recognition, Proc. SPIE 1383, pp. 391 -.10?., Boston, MA, November, 1990.

6. H. Das, 11. Zak, W. S. Kim, A. K. Bejczy, and 1'. Schenker, "Performance experiments with alternative advanced teleoperator control modes for a simulated Solar Maximum satellite repair," in Proc. SOAR '91 Symposium (Space Operations, Applications, and Rc.scale.h), Houston, TX, July 1991.

7. A. K. Bejczy and 7,.1:. Szakaly, "An 8-d.o.f. dual arm system for advanced teleoperation performance experiments," in Proc. SOAR '91 Symposium (Space Operations, Applications, and Research), 1 Iouston, '1X, July 1991; see also, S. Lee and A.K. Bejczy, "Redundant arm kinematic control based on parameterization," in Proc. 1991 1 EEE Intl. Conf. on Robotics and Autom., Sacramento, CA, April 1991.

FIGURES

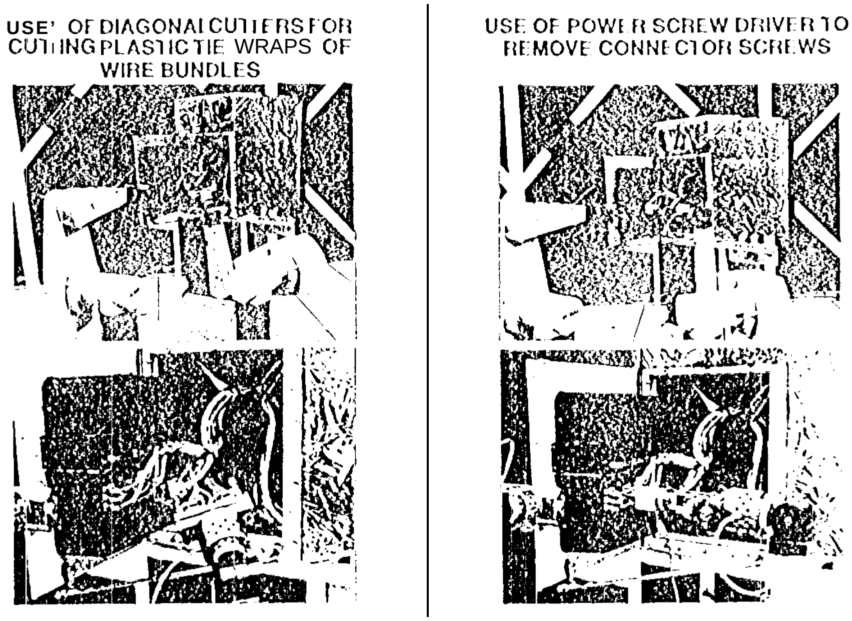

Fig. "1. Advanced teleoperation applied to the Solar Maximum satellite repair task [2, 6]

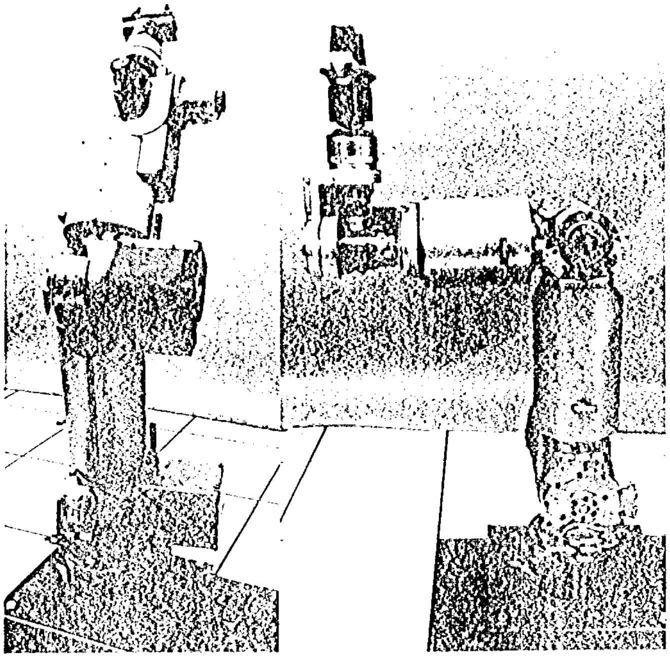

Fig. 2. 8-d.o.f. manipulator for advanced teleoperation experiments[6]

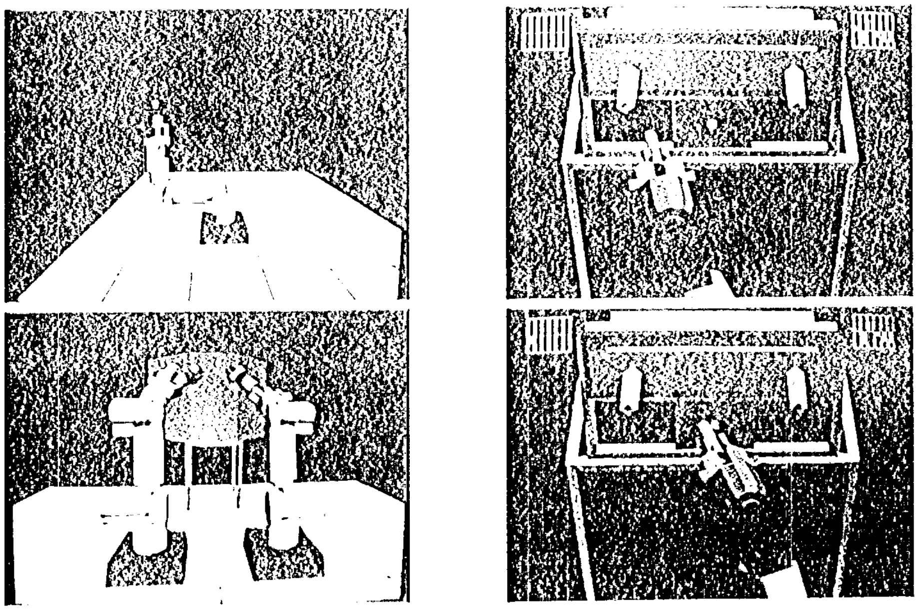

Fig. 3. Real-time graphics: (left) kinematic feasibility analysis for cooperative 8-d.of. arms and Solar Max satellite repair; (right) operater training for simulated peg-in-hole task, including visual force indicators and kinesthetic force feedback to hand-controller[3]